Title:
Go-around accidents and General Aviation safety

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Running head:
Go-around accidents

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Abstract
Introduction: Changes in General Aviation (GA) accident rates, specifically in the go-around phase, are examined by comparing the number of accidents, the proportion of fatal accidents and the proportion of certain causes of accidents over time.
Methods: Two sets of accidents from 2000 to 2004 and from 2013 to 2017 were extracted from the National Transportation Safety Board online database.
Results: Although the total number of GA accidents per landing significantly decreased over time, the proportion of fatal accidents in the go-around phase increased. Fatalities most often occurred in instrument meteorological conditions.
Conclusion: Advances in technology and training show improvements in GA accident rates but not for accidents in the go-around phase. Scenario-based learning is recommended to include specific instruction concerning the timing of go-around procedures in unstable flights.

Keywords: General Aviation, fixed-wing aircraft, landing, go-around, aviation training

Introduction to General Aviation safety

General Aviation (GA) is a part of civil aviation that has exhibited the highest accident and fatality rates (Boyd 2017; Li & Baker 1999). This safety concern has persisted for decades and several attempts have been made to understand and improve its safety record. Understanding GA is complex as its characteristics are also highly diverse.

Accident analysis has targeted specific aspects of GA to understand its safety record. For instance, it has shown different characteristics per type of aircraft, such as sports aircraft (de Voogt & van Doorn 2010) and helicopters (Taneja & Wiegmann 2003), different types of operations, such as emergency medical services (Baker et al. 2006), aerial application (van Doorn 2014; de Voogt, Uitdewilligen & Eremenko 2009) and instruction (Olson & Austin 2006; Baker et al 1996). Even within the same flight aviation rules (FAR), such as those for GA or air taxi and commuter aircraft, and only focusing on fixed-wing airplanes, research has pointed out geographical differences that greatly affect the safety of aviation operations (Thomas et al. 2000; Grabowski, Curriero & Baker 2002). Finally, the phase of flight is considered especially important with several studies focusing on the landing phase (e.g., Benbassat & Abramson 2002; Benbassat, Williams & Abramson 2005) to allow for specific safety recommendations.

The go-around

A go-around in aviation is an aborted landing commonly instigated by a dangerous situation on the runway or an unstable approach. The procedure to move from a landing to a take-off configuration is also practiced by student pilots and generally considered a challenging emergency maneuver (Baker et al. 1996; Dehais et al. 2017; Uitdewilligen & de Voogt 2009). Since the maneuver is meant to avoid a possible dangerous landing, accidents during the go-around phase are particularly unfortunate and suggest a lack of experience or skill on the part of the pilot.

Accidents during a go-around maneuver have been studied for airliners for which loss of situational awareness and possible improvements using enhanced vision systems have been suggested (Kramer, Bailey & Prinzel 2009). In addition, the role of economic pressures, i.e., the cost of a go-around for an air carrier, on risk taking was studied experimentally (Causse et al. 2019). Both enhanced vision systems and economic pressures are less relevant for General Aviation operations; however, the accident frequency in this segment of aviation is particularly high (Boyd 2017). Of all flight phases, landing accidents are reported as the most frequent and landings with a high-airspeed especially dangerous (Boyd 2019). This suggests that go-around maneuvers although challenging may assuage the landing accident rate if performed correctly.

FITS

Apart from increasing insight in the characteristics of accidents, several changes have taken place in GA that may positively affect the accident and fatality rates. They range from the introduction of airplanes with emergency parachutes (Alaziz, Stolfi & Olson 2017) to technological advances in the field of navigation, in particular GPS. Parallel to these developments, the Federal Aviation Administration has supported initiatives to improve training curricula, known as the FAA Industry Training Standards or FITS (Craig 2009; Summers et al. 2007) that should improve a pilot's ability to manage risk.

In 2007, the Federal Aviation Administration (FAA) started to develop FAA Industry Training Standards (FITS) for a generic commercial pilot syllabus (Craig 2009). It used a scenario-based methodology that should improve a pilot's ability to manage risk in scenarios such as a go-around (Summers et al. 2007). A recent study on go-arounds in commercial aviation suggests that decision-making, in particular the timing of the decision, is essential and that protocols for go-around decisions during unstable flights are frequently ignored and may explain accidents in this flight phase (Blajev & Curtis 2017). It is, however, not clear if FITS address these aspects effectively to reduce the accident rate in this flight phase.

The FITS program concentrates on scenario-based training, single pilot resource management and learner-centered grading. While in this model flight maneuvers are still a central part of flight training, the use of real-world scenarios is used to enhance the pilot's decision-making skills. The elements of single pilot resource management have direct or indirect relevance for landing and go-around procedures since they emphasize, for instance, situational awareness, risk management and task management (Summers et al. 2007).

An overall reduction in GA accident and/or fatality rates is difficult to determine due to the diversity of GA operations but is, on the other hand, expected in light of the developments in technology and training as well as an increased awareness and understanding of GA accidents. In the following study, we selected two sets of accidents from two different time periods for comparison. These time period precede and follow the introduction of FITS and span an era in aviation where, for instance, GPS technology has become particularly common in all of General Aviation. We limited our data to fixed-wing GA aircraft only and concentrated on one particular flight phase, the go-around. Pilots performing a go-around are likely to benefit from the advances in technology and training. Research on go-arounds has mainly proceeded in simulators and for pilots of airliners so that we have a reasonable understanding of the expected main causes but not whether this insight and its possible remediation has reached GA pilots.

In this study, we expect to see a positive impact on safety in General Aviation both in the number of go-around accidents, the proportion of fatal go-around accidents and the proportion of certain causes of go-around accidents over time as they may point to significant shifts in pilot practices. The results of this study may not only provide a better understanding of GA go-around accidents but also serve as a possible proxy for developments in GA safety more broadly.

We analyzed the causes and factors of 187 General Aviation go-around accidents from 2000 to the end of 2004 and compared these with 117 accidents from 2013 to the end of 2017. In both data sets the fixed-wing airplane was in a go-around phase when the accident occurred. The results may indicate whether the nature of go-around accidents in the USA has changed since the introduction of FITS, technological advances and increasing insight in the GA safety record.

Method

An aviation accident is defined by the National Transportation Safety Board (NTSB) as an occasion in which the aircraft was substantially damaged or destroyed, and/or, in which occupants or people on the ground were seriously injured or died as a result of the occurrence. Accidents resulting in minor injuries and only minor damage are reported as incidents and administrated by the Federal Aviation Administration (FAA).

All NTSB accident reports are made available online and may be accessed using the NTSB Aviation Online database using the CAROL (Case Analysis and Reporting OnLine) search query tool. Each accident has a factual report and a probable cause report that summarizes the findings of the NTSB investigator with a narrative statement, a set of findings that determines the cause and contributing factors of the incident as well as data on the pilot, aircraft, airfield and meteorological conditions.

United States General Aviation fixed-wing airplane accidents that took place during the go-around flight phase were extracted from the NTSB online database for the period 2000 till the end of 2004 and for 2013 to the end of 2017 (NTSB 2020). These periods were selected to allow for changes to become visible as a result of the introduction of the FITS program as well as technological changes in aviation. Accidents were identified using the "broad phase of flight" search tab in the database. Two cases from the first time period showed a different flight phase and were removed from the dataset. The narrative text of each accident was used to determine the reported reason for starting a go-around, the number of go-arounds attempted and, as far as possible, when the flight became unstable and when the decision to go around was made.

The Federal Aviation Administration provides denominator data of different kinds including number of aircraft, number of flight hours and number of landings. The number of landings is most relevant as denominator data for our dataset. It is noted, however, that landings are only counted for towered airports while GA flight are often found at non-towered airports. Unfortunately, the FAA does not differentiate between General Aviation and Air Taxi landings while in the latter two years of our dataset Commuter flights are also included in the number of landings, i.e., Flight Aviation Regulations (FAR) under Part 135 Commuter and Air Taxi. Although this still provides a reasonable comparison, some caution in the interpretation of these data is warranted.

In addition to comparing the number of landings per year, the FAA also allows for a differentiation between the number and type of engines of the aircraft. In our dataset, most airplanes had one reciprocating (piston) engine so it is useful to provide this detail in the denominator data in case it fluctuates differently compared to other types of engines.

We used Pearson χ^2-square analysis at the significance level of .05 to determine the significance of relations within the datasets. In analyses in which the expected cell frequencies were less than 5, a Fisher exact test was used. A logistic regression using fatal vs. non-fatal as categorical outcome was used with the categorical predictors found using Pearson χ^2-square analysis to determine relative risk ratios. Unlike the proportion-testing, the logistic regression adjusted for the contributions of the other variables. A Poisson regression analysis was used to predict the number of fatal go-around accidents based on time period (early vs. later) with the natural log of the fixed-wing landings as an offset.

Risk analysis

A risk analysis of go-around accidents is part of a broader analysis of risk in General Aviation. The number of accidents for fixed-wing aircraft, the number of accidents in the landing phase, and the number of accidents in the go-around phase each have different characteristics. As is shown in Figure 1 and table 1, the percentage of fatal accidents fluctuates significantly between these three groups and accidents in the landing phase have by far the smallest proportion of fatalities.

Figure 1 and table 1 show that between the two periods of study there is a drop in the number of landings. This drop is mirrored with a drop in total number of accidents. There is also a change in the percentage of fatal accidents in the second dataset, which is lower for the total number of accidents and for landing accidents but is higher for go-around accidents.

A Poisson regression analysis was used to predict the total number of go-around fatal accidents based on time period (early vs. later) and the total General Aviation fixed-wing landings during the same time period, with the natural log of the fixed-wing landings as an offset. The analysis revealed some evidence that fatal go-around accidents were .915 (95% CI 0 to 1.83) times more likely to occur in the later period compared to the early period, $p = .05$. However, the 95% CI included zero so we cannot make an inference as to whether the rate was higher or lower for both periods. The other variable failed to reach levels of statistical significance in the analysis.

Figure 1. Trends of GA fixed-wing accidents in landing and go-around phase

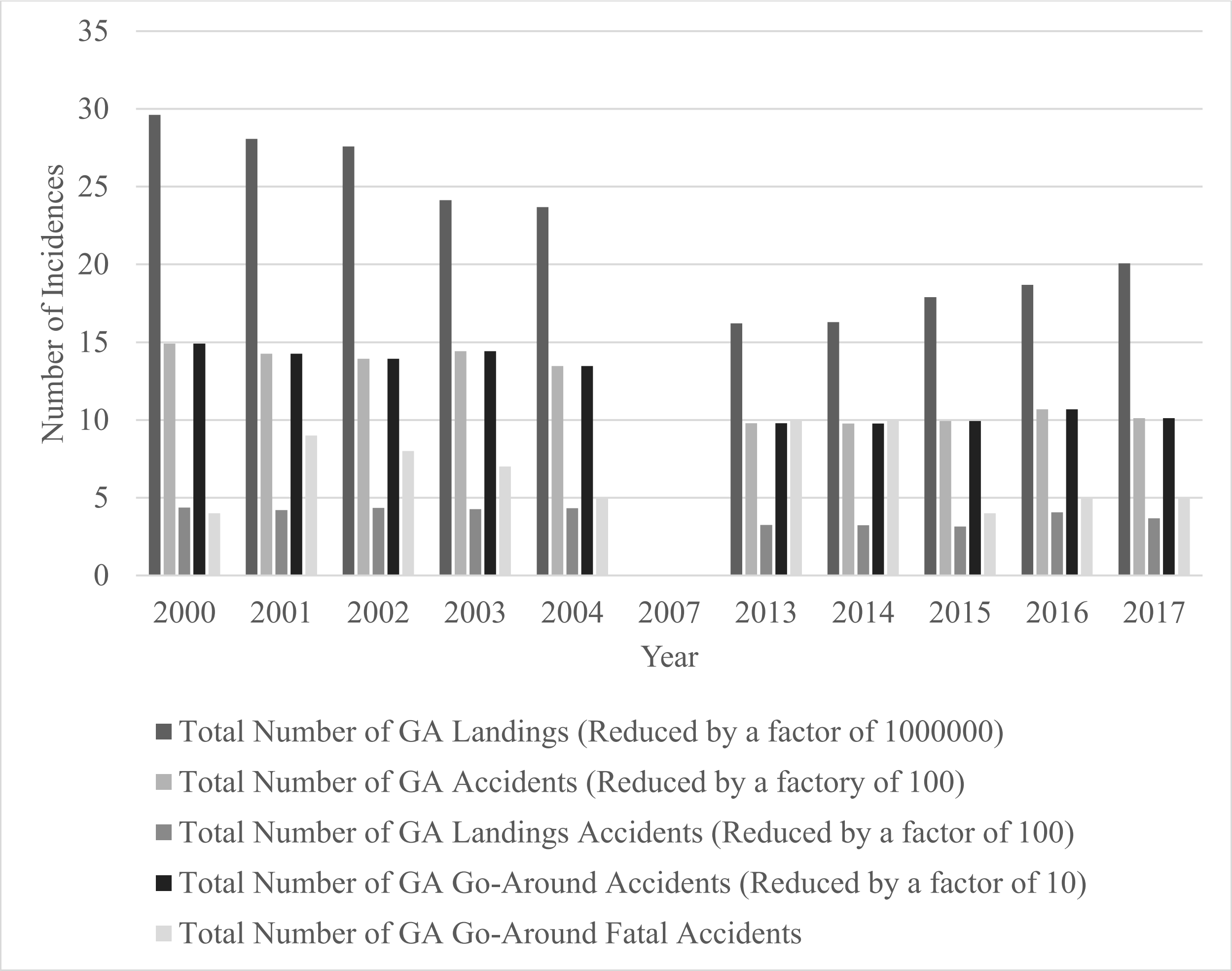

Table 1. Overview of number of landings and accidents per year for fixed-wing aircraft in the United States

	Total fixed-wing landings [SD]	**All go-around** accidents	**All fatal go-around** accidents	**All landing** accidents	**All** GA accidents
2000	37,914,142 [3.6]	38	4	436	1490
2001	35,011,549 [5.7]	36	9	420	1426
2002	36,321,419 [5.2]	41	8	434	1394
2003	31,959,886 [3.7]	38	7	426	1443
2004	32,171,301 [1.6]	34	5	433	1347

Total 2000-2004 (fatal)	173,378,297	187 (33/17.6%)	33 (17.6%)	2149 (41/1.9%)	7100 (1441/20.3%)
2013	24,239,819 [1.6]	29	10	324	979
2014	24,092,551 [1.6]	26	10	323	977
2015	25,884,484 [1.7]	17	4	315	993
2016 GA & Part 135	27,243,225 [1.7]	18	5	406	1068
2017 GA & Part 135	28,294,609 [1.6]	29	5	367	1012
Total 2013-2017 (fatal)	129,754,688	119 (34/28.6%)	34 (29.1%)	1735 (20/1.2%)	5029 (905/18.0%)

Results

There is strong relation between aircraft damage and fatality in both time periods (Table 2). This relation is not unexpected although previous studies have shown some exceptions to this seemingly obvious relation (de Voogt, van Doorn 2006a; de Voogt, Hummel Hohl, Kalagher 2021).

Table 2. Relation of fatal accidents and aircraft damage

Fatality\damage	Destroyed aircraft	Substantially damaged	Minor damage
Fatal accidents 2000-2004	28	5	0
Nonfatal 2000-2004	9	144	1
Fatal accidents 2013-2017	21	13	0
Nonfatal 2013-2017	2	81	0

Go-around fatal accidents were more prevalent at night in both time periods. Similarly, go-around fatal accidents were more prevalent in IMC rather than VMC conditions (Table 3).

Table 3. Proportion of fatal accidents in IMC and night conditions

Environment	2000-2004		2013-2017	
VMC (fatal)	166 (16)		102 (20)	
IMC (fatal)	21 (17)	$\chi^2 = 65.2351$, $p < 0.01$	17 (14)	$\chi^2 = 27.4026$, $p < 0.01$
Day/dusk (fatal)	157 (23)		120 (25)	
Night (fatal)	18 (10)	$\chi^2 = 19.3555$, $p < 0.01$	12 (9)	$\chi^2 = 13.6892$, $p < 0.01$

Aircraft with two engines had a significantly higher proportion of fatalities than those with one engine while turbine engine aircraft did not report any fatalities in the two periods under study. The ratio of fatal accidents among amateur built aircraft was not significantly different from other aircraft in the dataset. (See Table 4)

Table 4. Proportion of fatal accidents for twin-engine, turbine and amateur-built aircraft

	2000-2004		2013-2017	
Twin engine (fatal)	25 (9)	$\chi^2 = 6.6885$, $p < 0.01$	16 (9)	$\chi^2 = 6.647$, $p < 0.01$
Turbine/turbo prop engine (fatal)	5 (0)		6 (0)	
Amateur built (fatal)	12 (3)		14 (3)	

In the first period, most cases reported the purpose of the flight as personal or instructional and Fisher exact test revealed that the proportion of fatal instructional flights was significantly lower than the proportion of fatal accidents for all others combined. However, in the second period, this was not significantly lower. Business flights, flight tests, aerial observation, ferry flights, positioning flights and other purposes reported fewer than 5 fatal accidents and 5 or fewer nonfatal accidents in either time period.

Flight hours are not always reported in the NTSB accident reports. There were four accidents with missing data on pilot flight hours in the first time period and two in the second period, all of which were nonfatal accidents. Similarly, age was not reported in two cases, both in the first time period.

Pilot age ranged from 19 to 88 years old in the first period and from 17 to 79 years in the second period. Pilots in the United States have faced mandatory retirement at age 60, a rule that has been controversial (AMA 2004) and may be better addressed using flight hours. There was a significantly higher proportion of over 60 pilots in the first period but not in the second while those with more than 500 flight hours made up a significantly higher proportion of fatal accidents in both time periods. (See table 5)

Table 5. Purpose of flight and pilot characteristics

	2000-2004		2013-2017	
Personal flights (fatal)	123 (22)		79 (26)	
Instructional flights (fatal)	45 (3)	$p < 0.05$	29 (5)	$p > 0.05$
Pilot age <60 (fatal)	141 (17)		75 (18)	
Pilot age ≥60 (fatal)	43 (16)	$\chi^2 = 14.1638$, $p < 0.01$	42 (16)	$p > 0.05$
Total flight hours <500 (fatal)	74 (6)		52 (7)	
Total flight hours ≥500 (fatal)	109 (27)	$\chi^2 = 9.1247$, $p < 0.01$	63 (27)	$\chi^2 = 5.8219$, $p < 0.02$

From the findings in the NTSB reports, it was determined how many accidents were attributed to the pilot in command, to students or others. Additional factors for fatal accidents included spatial disorientation of which 3 occurred at night in the first time period and 4 were at night in the second period and all except one in the second period occurred during IMC conditions. One night-time IMC fatal accident in the second period also reported a “somatogravic illusion”, possibly exacerbated by the pilot’s consumption of antihistamine.

In the first period, a total of 42 accidents occurred after more than one go-around and 19 of these were part of go-around practice. In the second period, a total of 33 accidents occurred after more than one go-around and 8 of these were part of go-around practice. In both periods, the cases with multiple go-arounds that were not part of flying practice had a significantly higher proportion of fatalities than the remainder of flights that include practice flights and flights where the first go-around led to an accident. (See table 6)

In the first period 39 cases of which 16 fatal, it could not be established from the narrative statement when the decision to go-around was made. Although non-fatal accidents had at least 29 cases in which the decision was made during touchdown and 19 cases during the landing flare, with 2 and 1 cases respectively for fatal accidents, this difference was not significant ($p > 0.05$).

However, in the second period, with 33 cases of which 10 fatal for which it could not be determined, the timing of the decision proved significant. Non-fatal accidents had at least 20 cases in which the decision was made during touchdown and 10 cases during the landing flare, with 4 and 2 cases respectively for fatal accidents. This showed a significantly smaller proportion of fatal accidents occurring during the touchdown and flare than in other phases of the approach ($\chi^2 = 3.8742$, $p < 0.05$).

Table 6. Circumstances for a go-around and cause attribution

	2000-2004		2013-2017	
Danger on the runway (fatal)	10 (2)		11 (4)	
Go-around practice (fatal)	28 (2)		18 (2)	
Bounced landing (fatal)	8 (0)		14 (1)	
Missed approach (fatal)	64 (14)		35 (8)	
Loss-of-control (fatal)	40 (10)		79 (26)	
Weather (fatal)	26 (3)		25 (7)	
Spatial disorientation (fatal)	14 (7)		8 (8)	
Not maintaining airspeed (fatal)	56 (7)		20 (7)	
Pilot-in-command (fatal)	156 (30)		86 (7)	
Other (undetermined)	11 (7)		(8)	
More than one non-practice go-around (fatal)	23 (9)	$\chi^2 = 8.3287$, $p < 0.01$	14 (9)	$\chi^2 = 9.5723$, $p < 0.01$

A logistic regression was used to test possible interactions and to determine which categories significantly predicted fatality (Table 7). Accidents in IMC conditions and at night, twin and turbine engine aircraft, pilot experience and the presence of multiple non-practice go-arounds became part of Model 1, which controlled for time period. IMC conditions, flight hours above 500 hrs and the presence of a turbine engine remained significant significant predictors of fatality in this model. Flights into IMC remained a significant predictor of fatality in Model 2. There were no interactions with the time period that were significant.

Table 7. Results of two models of logistic regression

Statistical models	Model 1		Model 2	
	Estimate (Standard error)	**Odds ratio** [Confidence interval]	**Estimate** (Standard error)	**Odds ratio** [Confidence interval]
(Intercept)	-4.86^{*} (1.99)	0.01 [-3.89; 3.90]	-3.90 (2.69)	0.02 [-5.24; 5.28]
Attempt	0.54 (0.47)	1.72 [0.80; 2.65]	0.75 (0.66)	2.13 [0.83; 3.43]
Twin engine	0.12 (0.50)	1.13 [0.15; 2.11]	0.14 (0.69)	1.15 [-0.21; 2.50]
Turbine engine	-1.52^{*} (0.76)	0.22 [-1.27; 1.71]	-2.02 (1.06)	0.13 [-1.94; 2.21]
IMC conditions	2.72^{***} (0.53)	15.23 [14.19; 16.27]	3.23^{***} (0.77)	25.40 [23.90; 26.91]
Night conditions	0.74 (0.53)	2.09 [1.04; 3.14]	0.29 (0.78)	1.33 [-0.20; 2.86]
Flight hrs >500	0.87^{*} (0.39)	2.38 [1.61; 3.15]	0.67 (0.57)	1.95 [0.83; 3.07]
Time period	0.82^{*} (0.35)	2.26 [1.58; 2.95]	-0.94 (3.95)	0.39 [-7.35; 8.13]
Period*Attempt			-0.56 (0.98)	0.57 [-1.34; 2.48]
Period*Twin engine			-0.09 (1.03)	0.91 [-1.11; 2.94]
Period*Turbine engine			1.05 (1.51)	2.87 [-0.09; 5.82]
Period*IMC conditions			-1.04 (1.08)	0.35 [-1.76; 2.47]
Period*Night conditions			0.93 (1.13)	2.53 [0.31; 4.75]
Period*Flight hrs >500			0.37 (0.79)	1.44 [-0.11; 3.00]
Log Likelihood	-112.36		-111.23	
Deviance	224.73		222.45	
Number of observations	296		296	

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Conclusion

While it is possible to glean trends for General Aviation safety using a risk analysis, it also illustrates that at a more granular level, in this case the specific phase of flight, the numbers may show a significantly different pattern. It confirms the need in GA accident analysis to examine specific datasets that may help to understand how safety is changing over time.

General Aviation has the highest number of accidents for which about 20% are reported fatal (Boyd 2017). This proportion of fatal accidents is slightly lower for those in the go-around flight phase in the earlier period we studied but significantly higher in the later one. Although the total number of accidents concerning go-arounds in general aviation have declined between the two periods, remarkably few differences are found in the characteristics of the flight accidents involving go-arounds apart from the proportion of fatal accidents that increased. This finding is especially disappointing in light of efforts by the FAA to improve pilot training.

Go-around maneuvers are practiced regularly but result in relatively few fatal accidents for instructional flights, which is in line with other studies on student flights (Uitdewilligen & de Voogt 2009). The more recent period also showed a significantly smaller proportion of fatal accidents occurring during the touchdown and flare. The proximity to the ground and the associated lower incidence of a fatality has also been attested in other studies (de Voogt & van Doorn 2006b). There are also few cases in which dangers on the runway create circumstances in which a go-around is not successful. As expected, it is the pilot-in-command rather than the student or the circumstances on the ground who is attributed the cause of an accident, especially a fatal accident, in the go-around flight phase.

Significant correlations between fatality and IMC as well as fatality and twin-engine aircraft are reported but they are not necessarily specific for go-arounds as previous research indicates (e.g., Boyd 2015, 2017). The increased complexity of twin-engine airplanes and their higher landing speeds partly explains why these aircraft are also at higher risk during go-arounds (Boyd 2019). In addition, most twin-engine planes flew in IMC conditions in this dataset.

While go-arounds are challenging procedures, experience appears inversely related to the presence of a fatal accident. It is noted that total flight experience does not necessarily mean more experience with go-arounds, at most it is more likely. Still this result is counter-intuitive if lack of training is thought to be the primary underlying cause. According to previous studies, it is not necessarily the go-around itself but the timing that is important (Blajev & Curtis 2017). In most cases, we were able to determine when the go-around was initiated, but it remained unclear if this was long or shortly after a flight had become unstable. This element of go-arounds is not specifically mentioned in the training protocols initiated by the FAA, i.e., FITS, but if implemented may improve the overall effect of this initiative.

Both experienced and inexperienced pilots require practice of go-around maneuvers with a focus on the timing of the go-around decision. In the case of IMC and twin-engine aircraft this practice needs to be extended to multiple different circumstances. Scenarios as taught in FITS (Summers et al. 2007) should include situations in which spatial disorientation is actively addressed, perhaps first in a simulated environment but ultimately in an environment where the movement of and forces on the aircraft and pilot during a go-around are experienced as well. Importantly, the problem of spatial disorientation was more often reported for fatal accidents, compared to nonfatal, in both studies. This also translates to air carriers where spatial orientation has been reported as a primary concern in go-around mishaps (Dehais et al. 2017; Kramer et al. 2009). Scenario-based learning as supported by FITS, is an important first step to achieve increased safety for both experienced and inexperience pilots.

In sum, the investments made in training curricula as well as a better understanding of problems with go-arounds in the literature have not yet shown the desired results in the accident statistics. If go-arounds are used as a proxy for the progress in GA aviation safety, the changes in both the number and the proportion of fatal accidents leaves much to be desired. At the same time, it shows that an increase in the proportion of fatalities in one specific phase of flight is contrasted with that in another such as the landing phase. The advancements made in GA safety may only have seen their effect in certain types of accidents or phases of flight. Considering the diversity within GA, even if we only observe fixed-wing airplanes, the way forward is more likely a combination of specific and general improvements in training and regulations for which accident analyses continue to provide a guide as well as a monitoring device over time.

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